KGA519 PROJECT REPORT

Green infrastructure and green infrastructure planning: a review of concepts and practices with particular reference to Berlin, Germany.

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Greenway incorporating pedestrian walkway and cycleway adjacent to Spree River, Berlin.
(Source: R.J. Carne)

SUMMARY

The term 'green infrastructure' was probably first introduced by Charles Little in reference to greenways in the early 1990s (in the USA) (Sandström 2002). Shortly after, in the context of sustainable development, urban green space in general was termed 'green infrastructure' to put it on equal footing with grey infrastructure. Since that time the term has appeared frequently in the environmental planning and design literature. One of the earliest and most frequently cited definitions is provided by Benedict and McMahon (2006, p.1). They describe green infrastructure as 'an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife'. While there are numerous definitions, two elements occur throughout - *multifunctionality and connectivity* – these lend some commonality to what may at first appear as disparate definitions.

Multifunctionality represents the ability of green infrastructure 'to provide several ecological, socio-cultural, and economic benefits' (Hansen et al. 2015, p.9). It is considered central to the green infrastructure approach, and has been comprehensively described by the European Commission (2012). A broad range of potential benefits, falling into 4 categories – environmental, social, climate change adaptation and mitigation, and biodiversity - have also been identified (European Commission 2013). Multifunctionality can be considered a key characteristic of green infrastructure, its importance underscored by the fact that it has been identified as a planning principle (e.g. Rouse and Bunster-Ossa 2013).

The other common characteristic, connectivity, is also considered a planning principle by Rouse and Bunster-Ossa (2013). In its simplest form, connectivity is about linking 'hubs' to form a network (Benedict & McMahon 2002). Beyond this, it is about creating multi-scale links to connect urban, suburban, and rural landscapes, and across scales to connect site, neighbourhood, city, and region (Rouse & Bunster-Ossa 2013). This 'multi-scale approach', with an emphasis on connectivity, is an application of certain key principles deriving from the field of Landscape Ecology (Ahern 2007).

Importantly, green infrastructure makes a critical contribution to the three components of sustainability viz. environment, economy and equity. The multifunctional nature of green infrastructure is pivotal in this role, whether one is considering functions or benefits. Its components e.g. public parks and gardens, greenways, and waterways, comprise various elements. These components and elements can be collectively termed 'green infrastructure assets'. They take many forms, range across landscape scales, have diverse origins, and can be found in both urban and rural landscapes.

Green infrastructure planning has been described as 'a strategic planning approach that aims at developing networks of green and blue spaces in urban areas designed and managed to deliver a wide range of ecosystem services' (Hansen et al. 2015, p.9). It aims to create multifunctional networks across landscape scales, from regional to city to neighbourhood. It can be viewed as an activity within the field of landscape planning, and has links to urban planning, regional development planning and social planning.

The case study city, Berlin, has a strong focus on green infrastructure planning and has 'some of the most advanced and sophisticated urban greening policies and programs in the world' (SBEnrc 2012, p.21). Its green infrastructure assets are spread across the full range of land use types, from agriculture, woodland and water, to buildings, recreational areas and water.

Overall, some 44% of Berlin's total urban area consists of green spaces and waterways (Profé et al. 2012, p.7).

Berlin is involved in regional planning with the surrounding State of Brandenburg. Important planning provisions from a green infrastructure perspective include regional parks to protect the peri-urban landscape from urban sprawl, in addition to conserving land for recreational purposes (Hansen 2015). For Berlin itself, the centrepiece at the city-wide scale is the Land Use Plan, which provides for the future development of the city, including areas are to be retained as open space. In short, the Land Use Plan provides the framework for a city-wide green infrastructure characterised by both connectivity and multifunctionality.

Plans based on Berlin-specific environmental legislation are also important in green infrastructure planning. The Landscape Programme (LaPro) is of particular significance, being a key element in linking landscape planning (and green infrastructure planning, as part of that) with the statutory land use planning process. The strength of Berlin's green infrastructure planning lies in the fact that is embedded within the latter via the city's Land Use Plan. Green infrastructure planning is also informed by a number of informal plans, again via the Land Use Plan, giving it a broader basis than might otherwise be the case. Overall, Berlin has an effective, comprehensive and well-integrated green infrastructure planning program. It has 3 important properties viz. it is integrated within the statutory land use planning process; it has a sound ecological basis; and it gives expression to multifunctionality and connectivity.

Three examples of green infrastructure planning principles spanning the years 2006 to 2016 have been reviewed. The influence of landscape ecology is pervasive, particularly in regard to connectivity. Two additional planning principles (along with strategies) have been suggested. The first is: green infrastructure planning should emulate 'indispensable patterns' in both urban and rural landscapes; and the second: green infrastructure planning should be aligned with the statutory land use planning process.

A number of general and Berlin-specific research questions have been put forward. It is also suggested there is a need for a comparative case studies between cities, since studies across locations are relatively rare.

It is concluded that green infrastructure is a significant and increasingly influential concept. In dealing with this complex and multi-faceted concept, green infrastructure planning has several significant challenges, one of the more important is how to integrate it within the statutory land use planning process, or at the very least, how to maximise its influence on that process. At stake is not only the continued implementation of sustainable development, but also progress in the urgent task of climate change mitigation and adaptation.

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1. Introduction

This study presents a review of concepts and practices relating to 'green infrastructure' and 'green infrastructure planning'. The latter can take place in both rural and urban environments (e.g. Landscape Institute 2013; Firehock 2015). The main focus in this study is on urban environments, with Berlin as a case study. This city shows a vigorous commitment to the development of green infrastructure (Cloos 2004; Lachmund 2013), and has been described as having 'a long history of integrating nature into the built environment' with 'some of the most advanced and sophisticated urban greening policies and programs in the world' (SBEnrc 2012, p.21). Indeed, it is among the leading examples of 'biophilic cities', the latter described by Beatley and Newman (2013, p.3328) as 'cities that provide close and daily contact with nature'. It is in such cites that green infrastructure planning is generally well established, and importantly, tends to be well-integrated with statutory land use planning processes. Berlin is no exception to this.

Objectives are:

a) to clarify the nature and characteristics of green infrastructure and green infrastructure planning with particular reference to Berlin;
b) to identify general planning principles for green infrastructure; and
c) to formulate pertinent research questions with respect to green infrastructure planning.

In the following, methodology is first described (Sec. 2). Then, the concept of green infrastructure is reviewed, recent definitions noted and key characteristics identified (Sec. 3). The components and elements of green infrastructure are then listed under the rubric 'green infrastructure assets' (Sec. 4). This is followed by a discussion of green infrastructure planning (Sec. 5). This is done with reference to the planning literature and online planning documents, focussing on Berlin as a case study. Selected examples of green infrastructure planning principles are then discussed and elements derived from the field of Landscape Ecology noted (Sec. 6.1). Two additional principles, based on the literature and Berlin case study, are then suggested (along with possible strategies) (Sec. 6.2). Finally, questions for further research are set-out (Sec. 7).

2. Methodology

This research is a desktop study. Methodology comprises a case study built on an examination of online planning documents supported by a literature review. Both are intended to illuminate the nature and characteristics of green infrastructure and green infrastructure planning. Following the nomenclature of Deming and Swaffield (2011, p.37) the overall research strategy is descriptive (objective-inductive).

The literature review included published papers and books, both local and international, relating to green infrastructure and green infrastructure planning. Preference was given to peer-reviewed, published literature, although material from other reputable sources – for example, reports conducted or commissioned by government bodies or non-government

agencies – need to be considered in a study of this kind. This is not an exhaustive literature review, rather it is a 'first take' on what appears to be an extensive literature[1]. As it stands, the literature search was executed via on-line searches on the key words – 'green infrastructure' and 'green infrastructure planning' – using search functions on websites of the National Library and UTAS library. The search timeframe was 2006 to 2016. Google Scholar was also utilised using the same key words. Additional literature (no specific timeframe) was then selected from the reference lists of papers and books identified during the initial search. This was done to enlarge on certain points, provide additional substantiation where required, or introduce different (but related) perspectives. An example of the latter is 'biophilic urbanism'. There was also need to delve into the literature of Landscape Ecology to explain more fully some of the concepts and theory behind green infrastructure and green infrastructure planning. This was thought necessary when it become apparent that much of the literature used ideas and concept from the field of Landscape Ecology, often without appropriate citation (particularly in the area of green infrastructure planning).

The online documents were selected from the body responsible for planning in Berlin i.e. the Senatsverwaltung für Stadtentwicklung und Umwelt (Senate Department for Urban Development and the Environment). A judicious use was also made of online news comments on 'green' planning issues (sourced via Deutsche Welle's DW On-line).

Berlin was chosen initially on the basis that the city, as noted in the introduction, has a strong focus on green infrastructure planning. In many ways, it offers an exemplary example of such planning, and as such offers an opportunity to identify general planning principles (objective b of this study)[2]. Importantly, Berlin's planning website (http://www.stadtentwicklung.berlin.de) provides abundant information. Furthermore, as part of the GREEN SURGE[3] program, it has been the subject of a recent survey of urban green infrastructure planning (Hansen 2015).

3. Green infrastructure: concept, definition and key characteristics

The *Concise Oxford English Dictionary*, 11th Edition (2006, p.730) defines 'infrastructure' as the 'basic physical and organisational structures needed for the operation of a society or enterprise'. So, when the word 'infrastructure' is appended to 'green', the resulting phrase

[1] One recent PhD (Mell 2010) devotes 35 pages to a literature review on the green infrastructure concept. More recently, Ely and Pitman (2014) review the same in a report running to some 379 pages. Given the volume of literature in and around the green infrastructure field it became apparent that any future attempt at a more complete literature review would probably require a 'representative approach', possibly utilising citation network analysis (e.g. Lecy & Beatty 2012). This was underscored by the fact that Ely and Pitman's apparently extensive review (using the 'snowball method'; see Babbie 2001) did not cite at least one of the well-published and clearly authorative authors identified in this selective review, namely Mell (2008; 2010; 2016).

[2] There is no claim that Berlin is somehow typical in regard to green infrastructure planning. In fact, it is probably something of an anomaly, the current situation arising from a complex planning history, and in particular, a 'co-production' of science (ecology) and politics. This 'co-production' has been admirably charted by Jens Lachmund (2013).

[3] GREEN SURGE is a trans-national research project funded through the European Union's Seventh Framework Programme. The project is 'identifying, developing and testing ways of connecting green spaces, biodiversity, people and the green economy, in order to meet the major urban challenges related to land use conflicts, climate change adaptation, demographic changes, and human health and well-being' (Hansen et al. 2015: 4). In order to understand the current state of Urban Green Infrastructure (UGI) planning and governance in Europe, a comparative analysis of 20 cities - one of which is Berlin - has been completed.

elevates the importance of green spaces well-beyond what one normally thinks of as 'amenity value'. Indeed, the parks, greenways, vegetated vacant lots of cities, and the forests, vegetated river corridors, and nature reserves of rural landscapes are revealed in a new light viz. through the lens of green infrastructure these green spaces are best understood as part of the fundamental structural elements required to maintain society, rather than simply being a pleasant (and disposable) addition to engineered elements. The point is well-made by the City of Melbourne (2012, p.59) in describing green infrastructure as 'the network of natural landscape assets which underpin the economic, socio-cultural and environmental functionality of our cities and towns……'. Similarly, Civic and Sutra (2014, p.5) state the green infrastructure concept 'recognizes that nature – healthy ecosystems and the services they provide – is the basis of our societal and economic organization', and moreover, the 'preservation of natural capital and ecosystem services is necessary to maintain the correct functioning of our society and economy'.

The concept of 'green infrastructure' was first introduced by Charles Little (Sandström 2002)[4]. Little had put the view that 'creative land conservation' in the USA, via its promotion of an extensive system of greenways, was inventing 'an entirely new infrastructure category' (Little 1990, p.30)[5]. Some years later, in the context of sustainable urban development, it seemed necessary, according to Sandström (2002, p.380) to 'upgrade urban green space, preferably as a coherent planning entity green infrastructure, and accord it the same status as other physical urban structures'. With this new focus Sandström believed that 'urban planners would then widen their attention to the manifold functions of urban green spaces' (Sandström 2002, p.380). Since that time the term 'green infrastructure' has appeared frequently in the environmental planning/design literature (e.g. Ahern 2007; Chang, Li, Huang & Wu 2012; Orive and Lema 2012; Rouse & Bunster-Osse 2013; Austin 2014; European Commission 2015; Matthews, Lo & Byrne 2015), and, it is apparent that urban planners (and architects, landscape architects, engineers, and urban land managers etc.) are now more aware of the 'manifold functions of urban green space'. In Australia, this is evident in initiatives such as the Living Cities Alliance (Living Cities Workshop Report 2016). More generally though, the broader appreciation of the value of green space (and green infrastructure generally) is readily apparent in the area of climate change adaptation (e.g. Gill et al. 2007; Bowler et al. 2010; Jim, Lo & Byrne 2015; Mathews, Lo & Byrne 2015; Norton et al. 2015). It is here that the critical role for green infrastructure in, for example, mitigating heat stress, increasing the infiltration and retention of water, and enhancing the storage of carbon, is becoming increasingly recognised. Indeed, the European Commission

[4] Inevitably, there is some dispute over where and when the term 'green infrastructure' was first used. For example, Firehock (2015, p.58) suggest the term 'was first coined in Florida in 1994 in a report to the governor about land conservation strategies', whereas Pankhurst (cited Gill 2016) suggests the term was applied somewhat earlier in the context of water management and land use planning (in the US). According to Gill (2016) the term first appeared in the academic literature in 1995.

[5] This doesn't mean that extensive green spaces had not been created in urban environments before the events Little was referring to. Olmsted's 'Emerald Necklace' in the USA (1800s), and open space planning in the UK towns of Letchworth and Welwyn (early 1900s) are just two examples which may warrant the descriptor 'green infrastructure' (see Austin 2014). The work of Ebenezer Howard also deserves mention in this context, particularly the notion of juxtaposing green spaces and residential areas (Howard 1965). According to Mell (2008, p.71), the 'relevance of Olmsted and Howard cannot be underestimated when discussing green infrastructure'.

(2015) now recognises green infrastructure as an important part of 'nature-based solutions' for cities[6].

Benedict and McMahon (2006, p.1) define green infrastructure as 'an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife'. There are other more recent definitions – for example, the Victoria Institute of Strategic Economic Studies (VISES) (2015, p.3) describe green infrastructure as 'the green spaces and watersystems which intersperse, connect and provide vital life support for humans and other species within our urban environments', going on to state that it exists across a range of landscape scales, has multiple benefits for society and the environment, and includes 'features that are multifunctional, networked and natural'.

A selection of other definitions spanning the last decade are shown in Table 1. Two characteristics occur throughout viz. *multifunctionality* and *connectivity* (the latter explicit, or implicit in describing green infrastructure as a network). These characteristics are apparent in the two definitions noted above and in recent publications not listed in Table 1 – for example, European Commission (2013); Jim, Lo and Byrne (2015); Burgess (2015); Douglas and James (2015); Connop et al. (2016) and Mell (2016). Thus, it appears that multifunctionality and connectivity provide some commonality to what at first glance may appear as disparate definitions. The first – multifunctionality – represents the ability of green infrastructure 'to provide several ecological, socio-cultural, and economic benefits' (Hansen et al. 2015, p.9). The concept can also be viewed from a 'functions' and 'services' perspective – for example, Natural England (2006, p.22) suggest that multifunctionality refers to 'the potential for green infrastructure to have a range of functions' and 'to deliver a broad range of ecosystem services'. They consider it central to the green infrastructure approach, applying to such diverse areas as habitat provision and access to nature; recreation, movement and leisure; landscape setting and context; and flood attenuation and water resource management.

The concept of multifunctionality has been comprehensively described by the European Commission (EC) (2012). Their report first describes GI functions in terms of 4 broad roles, namely:

- Protecting ecosystem state and biodiversity;
- Improving ecosystem functioning and promoting ecosystem services;
- Promoting societal wellbeing and health; and
- Supporting the development of a green economy, and sustainable land and water management.

Then, the green infrastructure features that support these roles are identified – for example:

[6] Nature-based solutions are 'actions which are inspired by, supported by or copied from nature', and moreover, 'harness the power and sophistication of nature to turn environmental, social and economic challenges into innovation opportunities' (European Commission 2015, p.4). In addition to contributing to climate change adaptation and mitigation, nature-based solutions are directed toward enhancing sustainable urbanisation; restoring degraded ecosystems; and improving risk management and resilience.

- ecological corridors, greenways, ecological 'stepping stones', buffer areas, and sustainably managed agricultural land contribute to the role of *protecting ecosystems state and biodiversity;*
- restored habitats, water bodies and wetlands, urban trees and permeable pavement can contribute to *improving ecosystem functioning and promoting ecosystem services;*
- public parks, urban vegetation and wetlands can promote *societal wellbeing and health*.

As for the last role - *supporting the development of a green economy, and sustainable land and water management* – all the features noted above contribute to it, through their support for the first 3 roles (European Commission 2012, p.25).

Table 1: Definitions of green infrastructure 2006 to 2016

Author/s	Definition
Kambite and Owen (2006, p.484)	'connected networks of multifunctional, predominantly unbuilt, space that supports both ecological and social activities and processes'
Tzoulas et al. (2007, p.169)	'all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales'
City of Melbourne (2012, p.59)	'describes the network of natural landscape assets which underpin the economic, socio-cultural and environmental functionality of our cities and towns i.e. the green spaces, water systems and built environment landscapes which intersperse and increase connectivity, multi-functionality and landscape performance in urban environments'
European Commission (2013, p.7)	'strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings'
Landscape Institute (2013, p.3)	'the network of natural and semi-natural features, green spaces, rivers and lakes that intersperse and connect villages, towns and cities. Individually, these elements are GI assets, and the roles that these assets play are GI functions. When appropriately planned, designed and managed, the assets and functions have the potential to deliver a wide range of benefits-from providing sustainable transport links to mitigating and adapting the effects of climate change'
Ely and Pitman (2014, p.3)	'the network of green places and water systems that delivers multiple environmental, social and economic values and services to urban communities'

A complete listing with detailed descriptions of each can be found in the full EC report. A useful summary of the latter is provided by Ely and Pitman (2014). Suffice to say here, that the role of green infrastructure in supporting the systems (ecological, social and economic) upon which the human species depends is clearly extensive. Moreover, as indicated in the foregoing, there are a wide range of potential benefits (summarised in Table 2). Both its extensive reach and multiple benefits are expressions of 'multifunctionality'. As Connop et al. (2016, p. 99) have recognised in the urban context: 'One of the key strengths offered by urban green infrastructure (UGI) to city planners is its multifunctionality, being able to provide environmental, social and economic ecosystem service benefits'. It is also apparent that the characteristic of multifunctionality demarcates 'green' from 'grey' infrastructure, in that the latter is generally designed for a single, specific purpose. Finally, the importance of multifunctionality is underscored by the fact that it is identified as a green infrastructure planning principle by Rouse and Bunster-Ossa (2013) (see Sec.6) and others (e.g. European Commission 2010; Hansen et al. 2015). It is suggested that the multifunctionality principle 'calls on planners and designers to maximize value for the communities they serve by using green infrastructure to achieve seemingly disparate goals such as flood control, reduced dependence on imported energy, and improved public-health outcomes' (Rouse & Bunster-Ossa 2013, p.19). Certainly, multifunctionality deserves to be regarded as a key characteristic of green infrastructure.

Table 2: Potential benefits provided by green infrastructure

environmental benefits	– provision of clean water – removal of pollutants from air and water – pollination enhancement – protection against soil erosion – rainwater retention – increased pest control – improvement of land quality – mitigation of land take and soil sealing
social benefits	– better health and human well-being – creation of jobs – diversification of local economy – more attractive, greener cities – higher property values and local distinctiveness – more integrated transport and energy solutions – enhanced tourism and recreation opportunities
climate change adaptation and mitigation benefits	– flood alleviation – strengthening ecosystems resilience – carbon storage and sequestration – mitigation of urban heat island effects – disaster prevention (e.g. storms, forest fires, landslides)
biodiversity benefits	– improved habitats for wildlife – ecological corridors – landscape permeability

Source: European Commission (2013).

The other common characteristic – connectivity – is clearly a key characteristic in the sense that green infrastructure is by definition a network (see Table 1), hence, connectivity must be evident i.e. without connectivity there is no network. Connectivity has been discussed by a number of authors. For example, Benedict and McMahon (2002, p.7) describe a green infrastructure system as being comprised of 'hubs' and 'links' – the hubs 'anchor green infrastructure networks and provide an origin or destination for wildlife and ecological processes moving to or through it'. Hubs can include reserves, state forests, private farms and regional parks. *Connectivity* is evident as 'links' – these 'tie the system together and enable green infrastructure networks to work' (Benedict and McMahon 2002, p.8). Examples of links are conservation corridors, greenways and greenbelts.

This simple 'hubs and links model' has been restated as late as 2010 (Wickman et al. 2010). However, connectivity is much more than just an enabling element in what is a highly simplistic model. For example, Rouse and Bunster-Ossa (2013, p.20) suggest that 'connectivity encompasses both natural ecological functions such as providing habitat routes for wildlife and human ones such as promoting social equity by connecting people to green infrastructure'. They go on to describe connectivity as a planning/design principle (as noted above multifunctionality is also included; see Sec.6 for a fuller discussion), suggesting that as a principle, connectivity recognises 'that green infrastructure is most effective in providing services and benefits when it is part of a physically connected system across the landscape'. They suggest, furthermore, that to 'create a connected green infrastructure system at the landscape scale, planners and designers should establish physical and functional linkages across urban, suburban, and rural landscapes and across scales to connect site, neighborhood, city, and region' (Rouse & Bunster-Ossa 2013, p.19-20). In other words, connectivity is about creating multi-scale linkages, as well as linkages at any one scale. This means, for example, that city-wide green infrastructure needs to be linked to the regional landscape within which it is set. Creating linkages across scales does increase the complexity of planning in that as the landscape covered by the 'plan' gets larger there is generally a concomitant increase in the number of planning jurisdictions which need to be brought into the planning process (a good Australian example of this is the Murray Darling Basin Plan). Planning complexities aside, the notion of creating connections across scales is an important concept. According to Ahern (2007) the 'multi-scale approach' with an emphasis on connectivity is an application of certain key principles deriving from the field of Landscape Ecology[7].

[7] Landscape ecology arose from the European traditions of regional geography and vegetation science, with the term 'landscape ecology' being first introduced by the geographer Carl Troll in the late 1930s. It was developed more fully in the 1950s and was ultimately used to denote the analysis of the biophysical complex of interrelations governing different areas within a region (Troll 1950; 1966). Various other interpretations have arisen over the years (Forman 1995a). According to Turner (2005) one point of agreement in the numerous definitions is that landscape ecology's focus is on understanding the reciprocal interactions between spatial heterogeneity and ecological processes. The IALE (International Association for Landscape Ecology) (2009) describes landscape ecology as 'the study of spatial variation in landscapes at a variety of scales……', including 'the biophysical and societal causes and consequences of landscape heterogeneity' (IALE 2009). The historical development of the field has been briefly summarised by Forman (1995a) and Dramstad, Olson, and Forman (1996). A more comprehensive treatment can be found in Burel and Baudry (2003).

Rouse and Bunster-Ossa allude to the importance of the concepts of landscape ecology in green infrastructure planning, stating that in 'creating connected green infrastructure systems, planners and designers can draw on basic concepts of landscape ecology (patch, corridor, edge, and matrix as the large-scale structural components of landscapes)' (Rouse & Bunster-Ossa 2013, p.20). However, it is surprising that the works of Forman (1995a; 1995b) and Dramstad, Olson and Forman (1996) are not cited or referred to directly, since these are among the more important publications on landscape ecology and planning. The first author (Forman) considers the concept of connectivity in some depth, describing it as 'a measure of how connected or spatially continuous a corridor, network, or matrix is' (Forman 1995, p.38). This is 'structural connectivity' – there is also 'functional or behavioural connectivity' which refers to how connected an area is for a process, such as animal movement. Ahern (2007, p.270) takes up this more complex view in describing connectivity as:

> a property of landscapes that illustrates the relationship between landscape structure and function. In general, connectivity refers to the degree to which a landscape facilitates or impedes the flow of energy, materials, nutrients, species, and people across a landscape. Connectivity is an emergent property of landscapes that results from the interaction of landscape structure and function, for example: water flow, nutrient cycling and the maintenance of biological diversity

General planning principles for 'corridors and connectivity' (along with patches, edges and boundaries, and mosaics) are provided by the second authors (Dramstad, Olson & Forman). Planning principles are discussed further in Sec.6. For now, it is interesting to note that insights on connectivity, and other landscape ecological concepts (e.g. edges, patches, stepping stones) are finding there way into recent publications on green infrastructure planning – for example, Firehock (2015). The early reservations expressed by a number of authors (e.g. Hobbs, 1997; Bastian, 2001; Opdam, Foppen & Vos 2002)[8] regarding the application of landscape ecology to planning may turn out to be unfounded, particularly in the context of green infrastructure planning.

Finally, this brief discussion of green infrastructure **'**concepts, definitions and characteristics' must note the all-important sustainability-green infrastructure nexus. While the role of urban

[8] In referring to Forman's (1995b) general principles of landscape and regional ecology, Hobbs (1997, p.6) commented: 'when one peruses recent summations of landscape ecological principles one wonders how accessible or understandable they are to people who may wish to apply them to real landscapes'. It was also suggested that 'in its present condition, landscape ecology has surprisingly little to offer those wishing to plan and manage the landscapes of the future' (Hobbs 1997, p.6). Important questions are posed - how much landscape ecology finds its way into land-use planning decisions? Or landscape design? In short, Hobbs puts forward the view that much more needs to be done to link landscape ecology with planning. Similar sentiments were expressed by others. For example, Bastian (2001, p.764) suggested that there are 'essential deficits in the practical application of scientific results' (from landscape ecology to planning/design) and, more specifically, notes the challenge for landscape ecology in contributing to the elaboration of scientifically based ecological goals/landscape visions ('Leitbild') that are acceptable to human society. Opdam, Foppen and Vos (2002) ask the question: Why is so much knowledge on ecological processes not applied in spatial planning? The authors challenge landscape ecologists to 'bridge the gap between knowledge development and knowledge application' (Opdam, Foppen & Vos 2002, p.776).

vegetation in contributing to the goals of ecologically sustainable development (ESD) has been recognised for some time (e.g. Carne 1994), recognition of the role of green infrastructure in contributing to the broader goals of sustainable development is relatively recent. For example, Ahern (2007, p.282) puts the view that 'Green urban infrastructure is an evolving concept to provide abiotic, biotic and cultural functions in support of sustainability'. Abiotic functions include, for example, the maintenance of hydrological regimes and sequestration of carbon; biotic functions include the provision of habitat and fauna movement corridors; and cultural functions, physical recreation and environmental education. Here, the multifunctional nature of green infrastructure is again evident, and importantly, because 'this suite of functions spans an abiotic- biotic-cultural continuum – it is inherently more likely to enjoy a broad base of public support' (Ahern 2007, p.268). This, as the author points out, is essential for a successful urban sustainability program.

More recently, Rouse and Bunster-Ossa (2013) note the importance of green infrastructure to the three 'Es' of sustainability viz. environment, economy and equity, going on to describe the wide range of derived benefits[9]. Similarly, Civic and Sutra (2014, p.5) state: 'Nature-based green infrastructure solutions provide ecological, economic and social benefits, thus addressing the three crucial aspects of sustainable development'. The sorts of benefits these authors are referring to have been set-out in Table 2. The green infrastructure-sustainability link is also made by Quintas (2015) in organising green infrastructure functions in terms of the three 'Es'.

Thus, the creation and maintenance of green infrastructure can be seen as critical to sustainability. The multifunctional nature of green infrastructure is clearly pivotal in this role, whether one is considering functions or benefits. Indeed, Ahern (2007, p.282) suggests that for 'those who understand the green infrastructure concept, and its promise, the needs and opportunity to apply it in the pursuit of sustainability are quite profound'.

4. Components and elements of green infrastructure

The components comprising green infrastructure, along with their main elements, are shown in Table 3. Some of these have been mentioned in the preceding discussion (mainly under the rubric 'green infrastructure features', in keeping with the European Commission's terminology). They are also sometimes collectively referred to as 'green infrastructure assets' (e.g. City of Melbourne 2012; Mell 2016) in order to emphasis their value. It is evident that such assets take many forms and range across landscape scales, from the site (e.g. backyard) to regional scale (e.g. national park). Origins are similarly diverse, since green infrastructure may be 'created from scratch, modified from pre-urbanization natural bequest, generated on ruderal sites by spontaneous colonization, or inherited as remnant natural enclaves' (Jim, Lo and Byrne 2015, p.51). Waterways can also be considered a legitimate component of green infrastructure

[9] Rouse and Bunster-Ossa (2013) also suggest that a key question for planners and designers is how to measure benefits so as to demonstrate the value of green infrastructure for society. Many benefits can be quantified, for example, reduction in stormwater volume, increased property values, and open space access, however, benefits such as improved aesthetic quality, while important, are much harder to measure.

(City of Melbourne 2012; Mell 2016)[10]. Elements include wetlands (natural and constructed), ponds and lakes, and day-lighted streams (Table 3).

Table 3: Green infrastructure assets

Components	Elements
public parks and gardens	urban parks, open space reserves, cemeteries and formal gardens
greenways	river and creek corridors, cycleways and routes along major transport corridors (road, rail and tram)
residential and other streets	street verges and associated open space pockets
sports and recreational facilities	ovals, golf courses, school and other institutional playing fields, and other major parks
private/semi private gardens	including shared (communal) spaces around apartment buildings, backyards, balconies, roof gardens and community (productive) gardens
green roofs and walls	roof gardens and living walls
squares and plazas	including public and private courtyards and forecourts
natural green space	including national parks and nature reserves, and coastal margins
waterways	wetlands, ponds and lakes, day-lighted streams, vegetated swales and drainage corridors, infiltration basins, and mangroves
utility areas	quarries, airports, and large institutional and manufacturing sites (also includes unused land reserved for future use)
agricultural and other productive land	including vineyards, market gardens, orchards and farms

Source: Adapted from Ely and Pitman(2014) and SBEnrc(2012).

[10] The term 'blue-green infrastructure' is sometimes used in the context of urban water management to draw attention to the fact that water is being considered in concert with green infrastructure (e.g. Everett, Lawson & Lamond 2015). Other authors (e.g. Mell 2016) prefer to consider waterways as a component of green infrastructure at the outset. This is the view adopted in this paper.

As Tzoulas et.al (2007) and the European Commission (2013) note, green infrastructure can also be a feature of the rural landscape. In this context, typical components could include natural green space, utility areas and greenways. However, all the components shown in Table 3 could contribute to 'urban green infrastructure' - much depends on the scale at which the green infrastructure assets are being considered. For example, the Royal National Park between Sydney and Wollongong could be considered, at the regional scale, to be an element in the green infrastructure of both cities. Similarly, if one considers 'Canberra the city', numerous parks and gardens and the inner hills and ridges come to mind as green infrastructure. However, if the context is enlarged to the Australian Capital Territory, the mountains and bushland of an adjacent national park (Namadgi NP) can be viewed as an integral part of Canberra's green infrastructure (particularly since much of the catchment for the city's water supply lies within the Park).

5. Green infrastructure planning

5.1 Definition and context

As Thompson (2007, p.11) points out, 'it is no easy task to define planning precisely, nor indeed to find a definitive term to describe it'. While this is partly due to the fact that planning 'is a complex and continuously evolving concept' (Thompson 2007, p.25), it is also a consequence of a fundamental division between those who define planning 'according to its object (producing and regulating the relations of people and structures in space) and those who do so according to its method (the process of decision making as it relates to spatial development)', this in turn leading to 'two largely separate sets of theoretical questions and priorities that undermine a singular definition of planning' (Fainstein & DeFilippis 2016, p.1). Given this background it is not surprising that concise definitions of 'green infrastructure planning' are rarely found in the literature. One of the very few is provided by Firehock (2015, p.26) who suggests that the 'recognition of the need to plan for conserving our natural assets has led to the field of green infrastructure (GI) planning' - the latter defined as 'a strategic landscape approach to open space conservation, whereby local communities, landowners and organizations work together to identify, design and conserve their local land network, in order to maintain healthy ecological functioning' (Firehock 2015, p.25)[11].

Another more comprehensive definition, put forward by Hansen et al. (2015) and referring specifically to *urban* green infrastructure planning is as follows:

> a strategic planning approach that aims at developing networks of green and blue spaces in urban areas designed and managed to deliver a wide range of ecosystem services. Interlinked with green infrastructure planning on a landscape scale, UGI planning aims at creating multifunctional networks on different spatial levels, from urban regional to city and neighbourhood planning. Due to its integrative, multifunctional approach, UGI planning is

[11] Firehock goes on to set-out six steps in creating a green infrastructure plan - these include 1. Set goals 2. Review data 3. Make assets map 4. Assess risks 5. Determine opportunities 6. Implement Opportunities. While Firehock's work is useful in terms of showing how a physical GI plan/map can be made, it says little about the overall planning context within which GI planning is placed. Indeed, this author leaves the impression the GI planning is a more-or-less discrete activity, developed outside the formal planning process and at best supplementing and informing the latter at various stages. This may be the situation in the US where the author works, however, as this study shows this not the case in Berlin.

> capable of considering and contributing to a broad range of policy objectives related to urban green space such as conservation of biodiversity, enhancing ecosystem services for human health and well-being, adaptation to climate change, and supporting the green economy (Hansen et al. 2015, p.9).

Other authors prefer to avoid definitions per se, and instead concentrate on providing insights to the field from various perspectives (e.g. Sinett, Smith & Burgess 2015), in this way capturing some of the complexity of this emerging, and undoubtedly, important field of planning.

The view taken by the present author is that green infrastructure planning is best viewed, at the outset, as existing and/or developing within a larger planning context, a representation of which is provided in Figure 1. Green infrastructure planning is considered here as an activity within the field of 'landscape planning'. The latter is one of the major areas of environmental planning (Marsh 1983), and has the overall goal of providing a rational basis for guiding land use change. More specifically, it is directed toward creating landscapes that 'are safer and healthier as human habitats, more resilient to deteriorating forces, and more consistent or harmonious with natural processes, features, and systems than would be possible in an unplanned world' (Marsh 1983, p.21-22). Marsh was writing well before the advent of what is now known as 'green infrastructure planning', nonetheless, this framing of landscape planning is entirely consistent with what is generally understood as green infrastructure planning. However, landscape planning is clearly the 'larger' activity, being concerned with matters beyond what is commonly the focus of green infrastructure planning (e.g. forecasting environmental impacts, hazard assessment). For this reason, Figure 1 places green infrastructure planning within the context of landscape planning. It is shown as a dashed line because as a subfield it is relatively under-developed in comparison to the other 'planning subfields' shown in Figure 1. It is noted, however, that within complex planning regimes such as that of Berlin, green infrastructure planning may not be recognised by that title. Rather, it is simply part of 'landscape planning' (as shown in Figure 1), the latter itself embedded within the overall land use planning process (as explained in the following case study).

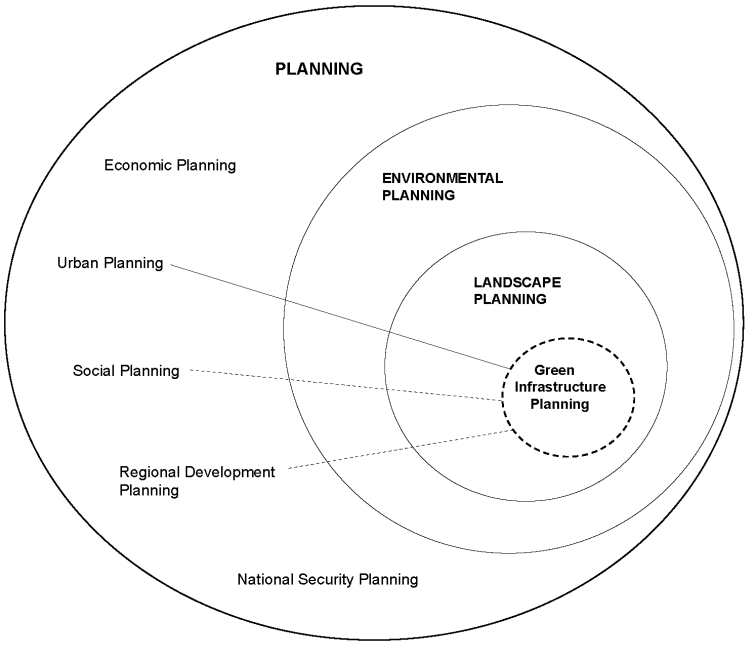

Figure 1: Green infrastructure planning is an activity within the field of Landscape Planning, with linkages to other planning subfields.

From a broader perspective, environmental planning is but one area within the broad field of Planning, the others as noted by Friedman (1987) are also shown in Figure 1. Of these, urban planning has the most direct connection with green infrastructure planning (Figure 1). However, large scale green infrastructure planning which extends beyond the urban periphery is, in some situations, linked to regional development planning. A good example of this is the protection of 'green wedges' in the Melbourne 2030 plan (Department of Infrastructure 2002). Social planning is also linked to some degree via the connection between green infrastructure and the health of urban populations. This important connection has been explored recently by Oliveira and Thompson (2015) and Coutts (2016).

5.2 Berlin case study

5.2.1 Location, population and biophysical setting

Berlin is Germany's largest city and centre of the Berlin-Brandenburg Metropolitan Region. It is located in north-eastern Germany some 180 km south of the Baltic Sea, 190 km north of the Czech-German border, and 89 km west of Poland (around latitude 52° 31` N; longitude 13° 24` E) (Figure 2). Population in 2015 was 3,563,000 (UN-Habitat 2016). This is expected to increase to 3,654,000 by 2025. If the urban area outside the 'core' city is included i.e. the larger urban zone extending into the Berlin-Brandenburg Metropolitan Region, the total population is somewhat larger, in 2012 standing at 5,097,712 (Hansen 2015) (comparable 2015 figures were not available at the time of writing).

Figure 2: Berlin is located in NE Germany within the Berlin-Brandenburg Metropolitan Region (Source: Britannica Atlas - Germany 2009).

The city is situated on the edges of the Tetlow and Barnim plateaus within a broad glacial valley traversed by the Spree River (Senate Department for Urban Development and the Environment 2016). The latter runs through the city itself (Figure 3). During the initial period of settlement, less fertile soils were planted to forest, whereas the better, moister soils were developed as meadows and fields (Senate Department for Urban Development and the Environment 2016). The city itself is built mainly on sandy glacial soil, today standing within an extensive area of forest-rimmed lakes (Figure 4). Berlin covers an area of some 88,966ha (Hansen 2015). If the larger urban zone is included the figure is 1,746,975ha. Length of the (core) city border is 234km and greatest E-W and N-S expanse is 45km and 38km respectively (Berlin.de 2014). Altitude ranges between 34 to 60m asl. Highest natural elevation (the Müggelberge) is 115m. Land use categories with percentage area are shown in Table 4.

Figure 3 (above): Spree River (Source: R.J. Carne)

Figure 4 (opposite): The Grünewald (Green Woods), part of Berlin's extensive 'forest-lake' landscape setting. Spandau and Charlottenberg are city boroughs (Source: Google Earth 2012).

5.2.2 Green infrastructure assets

Berlin's green infrastructure assets are spread across the full range of land use types shown in Table 4. In some cases they represent the whole land use type, in other cases they are present as particular components or elements. Green infrastructure as a 'whole land use type' is represented by agriculture, woodland and water, amounting to 29.2% of the total area. The other land use categories include at least some green infrastructure components or elements. For example, the largest category 'buildings' (41.4%) includes green roofs and walls, interior courtyard and balcony gardens (Figures 5 & 6); for 'business/industry', green forecourts are a possibility, as are outdoor lunch areas; recreational areas include public parks and gardens, city squares, playing fields and golf courses (Figures 7 & 8); and

the transportation category will incorporate green transport corridors (road and rail) along with street verges and tree-lined avenues (Figure 9). In the 'other area' category it may be possible to find small garden allotments (on land awaiting redevelopment, for example).

Table 4: Land use in Berlin: % of total area in 2011

Land Use	% of total area
Buildings	41.4
Business/industry	0.9
Recreational areas	11.9
Transportation	14.9
Agriculture	4.2
Woodland	18.3
Water	6.7
Other areas	1.7

Source: Berlin.de (2014)

Figure 5: Rooftop gardens, including small trees, are a part of Berlin's green infrastructure (Source: R.J.Carne).

Figure 6: Courtyard gardens, also a part of Berlin's green infrastructure, exhibit a surprising luxuriance. This one has a tree canopy, shrub understorey (2 layers) and ground cover (Source: R.J.Carne).

Figure 7: Public parks and gardens. Tiergarten Park (centre of image) is one of the best known and most popular parks in Berlin. The park comprises some 255ha, with over 50 tree species represented. The Straße des 17. Juni marks its east-west axis leading to the Brandenburg Gate (see Fig. 8). The Tempelhof airport (bottom RHS) was turned into a 380ha public park in 2010 (the Tempelhofer Freiheit) (Source: Google Earth 2012).

Figure 8: Looking east over portion of the extensive Tiergarten Park - view from the Siegessäule (Victory Column) down Straße des 17. Juni (17th June Street) to the Bradenburg Gate with 'former' East Berlin beyond (Source: R.J. Carne).

Figure 9: Tree-lined avenues. The Unter den Linden ('under the linden trees') – a beautiful shady avenue in the Mitte district, extending east from the Brandenberg Gate (Source: R.J. Carne).

The city's green infrastructure has been categorised in a number of ways – for example, whether it is 'designed', 'natural' or 'made by people' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015). Table 5 shows the mix of components and elements in these categories.

Table 5: Categorisation of green infrastructure assets

Category	Components/elements
designed green spaces	new and historic parks & recreational facilities, city squares, leafy streets, and tree-lined avenues.
natural landscapes	forests, lakes, nature reserves, conservation areas and urban wildernesses.
spaces made and used by people	farmland, allotments, community gardens, beach bars, educational sites.

Source: Senatsverwaltung für Stadtentwicklung und Umwelt (2015)

Overall, Berlin shows a marked proclivity toward the creation and retention of green space with 44% of the total urban area consisting of green spaces and waterways (Profé et al. 2012, p.7). This includes more than 2,500 public green and recreation spaces occupying some 6,400ha. Recent additions include the 380ha Tempelhof airport, which was converted to a park in 2010, and the 32 ha Gleisdreieck Park (on the site of a former freight depot) opened in 2011 (Braun, 2011). In terms of green area per million people, the 2014 figure for Berlin was much larger than for Australian cities of comparable population size - more than six times the figure for Melbourne, and more than 4 times that of Sydney (UN-Habitat 2016, p.210).

The origins and evolution of the planning regime responsible for Berlin's green infrastructure has been described in detail by Lachmund (2013), suffice to say here, the key drivers are thought to be: a historical and cultural concern for the environment amongst Berlin residents; the urban heat island effect (pronounced in inner Berlin); a focus on quality of life (Berlin seeks to promoting a relaxing and pleasant atmosphere); and waterway protection (the city protects its waterways for their aesthetic and environmental value, as well as for drinking water) (SBEnrc 2012).

5.2.3 Overview of spatial planning: Berlin and Region

Berlin is involved in regional planning with the surrounding State of Brandenburg (see Figure 2). The State Development Programme for the Berlin-Brandenburg Region is the overall planning strategy for the region, including the development of open space (Hansen 2015). This strategy is implemented through the State Development Plan Berlin-Brandenburg. The latter provides the framework for regional spatial development, defining the overall spatial structure and containing general objectives for the development of open space and built areas. Both instruments are legally binding, and importantly, from a green infrastructure perspective, provide for a chain of 8 regional parks to protect the peri-urban landscape from urban sprawl emanating from Berlin, in addition to conserving land for recreational purposes (Hansen 2015).

For Berlin itself spatial planning ranges across scales, from city-wide to city-block. Formal planning documents are based on:

- federal planning legislation (Land Use Plan and Local Development Plans);
- Berlin-specific planning regulations (Sectoral Development Plans, Intermediate Area Plans); and
- Berlin-specific environmental legislation (Landscape Programme and Local Landscape Plans) (Senatsverwaltung für Stadtentwicklung und Umwelt 2015).

The hierarchy of plans, arranged in descending order of scale (from regional to local area) is shown in Figure 10. The centrepiece at the city-wide scale is the Land Use Plan. This plan must be consistent with the abovementioned regional plans. It provides a framework for the city-wide Sectoral Development Plans, for Intermediate Area Plans, and for legally binding Local Development Plans for the city boroughs (Senatsverwaltung für Stadtentwicklung und Umwelt 2015) (Figure 10). In short, the Land Use Plan provides for the future development of the city, showing which parts of the city are intended for housing, industry, commerce, infrastructure and other urban uses. Its also shows which areas are to be retained as open space. All the aforementioned plans are supplemented by a large number of informal planning documents for specific areas or subject matters e.g. Area Planning Concepts and Urban Design Schemes (Figure 10).

Important in the planning of green infrastructure are the plans based on Berlin-specific environmental legislation. Of particular significance is the Landscape Programme (Landschaftsprogramm) (LaPro). This will be discussed in more detail in the following section, suffice to say here, the LaPro deals 'with the protection of natural resources, the enlargement and enhancement of open spaces within the city, with nature and landscape conservation, the improvement of living conditions for the inhabitants and the preservation of characteristic urban landscapes' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.8). In addition, it 'provides the ecological basis for the Land Use Plan and for the ecological evaluation of proposed modifications to this plan' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14), and moreover, is a key element in linking landscape planning (and green infrastructure planning, as part of that) with the statutory land use planning process.

5.2.4 Urban green infrastructure planning

As part of the GREEN SURGE project (see Sec. 2), Hansen (2015) has identified a number of important themes in Berlin's green space planning. These include the protection of biodiversity and the creation of habitat networks, and adaptation to climate change. The social relevance of urban green space and new strategies for increasing the quality and robustness of the latter are also given attention. Hansen cites a number of planning documents pertinent to green infrastructure planning . These include:

- Landscape Programme (LaPro) and Biodiversity Strategy;
- Urban Development Plan-Climate;
- Urban Landscape Strategy; and
- Programme for Mixed Forests

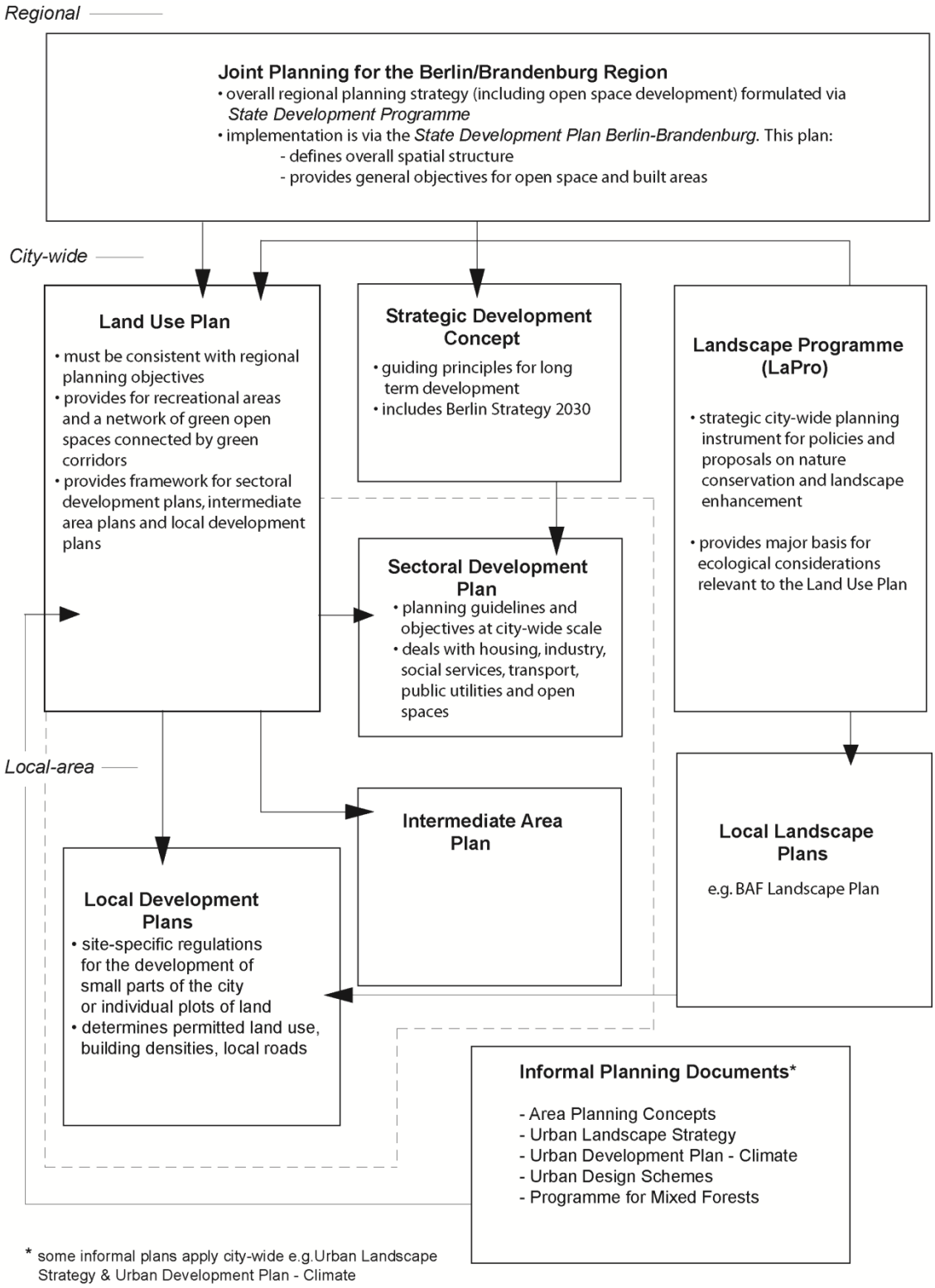

Figure 10: Berlin's plan hierarchy – regional to local area.
Source: adapted from Senatsverwaltung für Stadtentwicklung und Umwelt (2015)

A summary description of these plans is provided in Table 6. However, Hansen's analysis, while providing a useful snapshot is somewhat deficient in not explicitly recognising the central role of the Land Use Plan in green infrastructure planning[12]. It is this plan which provides for large recreational areas and a network of green open spaces. More specifically, it contains an open space strategy which aims, among other things, to 'knit together' the open space pattern by using a 'large number of green corridors' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). This is clearly an expression of 'connectivity', one of the key characteristics of green infrastructure identified in Section 3. The other characteristic identified was 'multifunctionality'. This is evident also, since the Plan will improve accessibility to 'large recreational landscapes on the outskirts of the city from major housing areas' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). This relates directly to the role of green infrastructure in 'promoting societal wellbeing and health' as identified by the European Commission (discussed in Section 3). Finally, green corridors will 'run alongside most of the water courses throughout the city' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). This is very likely an attempt to realise the role of green infrastructure in 'protecting ecosystems state and biodiversity' in the context of riparian ecosystems. Again, this role has been recognised as an aspect of multifunctionality (see Section 3). In short, the Land Use Plan provides the framework for a city-wide green infrastructure characterised by both connectivity and multifunctionality.

As indicated in Figure 10, the plans Hansen has selected are in fact supplementary to the Land Use Plan. However, this does not mean they are unimportant. For example, the LaPro, as noted in the previous section, provides the ecological basis for the Land Use Plan as well as an evaluation of proposed modifications to it. In addition, and as indicated in Figure 10, the LaPro influences Local Development Plans via the Land Use Plan. This is implemented through the requirement to consider the objectives and measures set-out in the LaPro. The fact that the LaPro is legally binding for public authorities enhances the efficacy of this requirement.

The LaPro also contains a General Urban Mitigation Plan which provides 'a city-wide strategy for the compensation of adverse impacts on the natural environment and landscape which cannot be compensated locally on the sites zoned for development' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). In such cases compensation measures are directed toward certain priority areas. For example, the developers of the Potsdamer Platz were required to pay 22 million euro toward the construction of the Gleisedreiek Park (Braun, 2011).

[12] This 'deficiency' possibly stems from the nature of the Green Surge project - in survey of 20 cities there are clearly constraints on the time and resources that can be applied to any one planning regime. The researchers have acknowledged as much, stating that their research approach is limited by 'the narrow selection of documents and desk study material', nonetheless, the 'chosen approach was adopted for reasons of timing and practicability' (Hansen et al. 2015, p.5). This situation does, however, illustrate the hazards of the selective use of planning documents, particularly if taken out of context i.e. considered them separately from the planning regime in which they are set. It also shows the central dilemma of cross-case studies vs. case studies i.e. is it better to do an intensive study on a single or several cases (a case study) or conduct a more superficial study using a larger sample (a cross-case study)? This methodological issue has been discussed by various authors (e.g. George & Bennett, 2005; Gerring, 2009).

Table 6: Plans pertinent to green infrastructure planning in Berlin*

Planning Document	Summary description
Landscape Programme (LaPro)	– based on the Berlin Nature Protection Act – a strategic landscape plan consisting of 4 components viz. ecosystem and environmental protection; protection of biotopes and species; landscape scenery; and recreation and the use of open space. – contains the General Urban Mitigation Plan which defines priority areas for compensation measures. – is legally binding for public authorities.
Urban Development Plan-Climate	– goal is to preserve the quality of life in the face of climate change and to improve it wherever possible. – is concerned with the spatial and urban planning aspects of climate in Berlin. While its main focus is on adapting to climate change, it includes efforts to protect the climate as well. – central to the adaptation process are strategies of conversion, improvement and conservation of existing structures – the starting point is the built city *with its green and open spaces.*
Urban Landscape Strategy	– goal is to enhance the structure of existing green space. – centred on 3 themes – Beautiful City, Productive Landscape and Urban Nature. – main themes are quality of life and horticultural heritage; social functions of urban green space; productive urban landscape; DIY culture and creativity of citizens; nature experience; and water management and biodiversity. – is non-binding, but generally approved in the current socio-political milieu.
Programme for Mixed Forest	– documentation is entirely in German, however Thierdorfer (2015) indicates it is part of the Urban Landscape Strategy. It appears to be concerned with multiple-use forestry with an emphasis on climate amelioration and protection of Berlin's water supply.

Source: Hansen (2015); Senatsverwaltung für Stadtentwicklung und Umwelt (2014 & 2015); Senatsverwaltung für Stadtentwicklung (2011); Thierdorfer (2015).

* the responsible government body in each case is the Senate Department for Urban Development and the Environment.

The other plans identified by Hansen (2015) viz. Urban Landscape Strategy, Urban Development Plan-Climate and Programme for Mixed Forest belong to a group of plans termed 'informal planning documents' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015) (Figure 10). These also influence the content of the Land Use Plan, bringing to it a diversity of considerations including climate change adaptation, social functions of urban green space, urban agriculture, and multiple-use forestry (Table 6).

Another significant plan not identified by Hansen (2015), but cited in relation to green infrastructure planning (Ahern 2007) and biophilic urbanism (SBEnrc 2012) is the Biotope/Green Area Factor (BAF) program. The BAF dictates the percentage of total land that should

incorporate vegetation to provide an ecologically-effective surface. The goal of the program is to counteract 'creeping impermeability' and is 'based on the principle that modest, incremental and decentralized green infrastructure can have a significant cumulative effect to improve the urban ecology' (Ahern 2007, p.280). The BAF is defined in the BAF Landscape Plan (Cloos 2004), the latter falling under the aegis of Local Landscape Plans (Figure 10). From there, it is taken into account in site-scale developments in concert with Local Development Plans. As Cloos (2004, p.5) describes it: 'The objective is to achieve the BAF no matter what changes are made to building land so as to strengthen ecosystem functions. In real terms this means planting greenery for facades and/or on roofs, and re-opening the surfaces in courtyards for the creation of green areas and to allow rain water seepage'. Clearly, this is consistent with the contemporary understanding of green infrastructure development.

5.2.5 Summary and conclusion

The strength of Berlin's green infrastructure planning lies in the fact that is embedded within the statutory planning process via the city's Land Use Plan. The latter is concerned (among other things) to provide directives with respect to green space planning. Importantly, the Land Use Plan is informed by the Landscape Programme, which also has statutory weight and 'provides the major basis for ecological considerations relevant to the Land Use Plan' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). This gives it – both the Land Use Plan and green space directives within it - a sound ecological basis. Furthermore, a concern for the key characteristics of green infrastructure – multifunctionality and connectivity – are evident in the Land Use Plan.

In addition, green infrastructure planning is informed by a number of informal plans, again via the Land Use Plan (see Figure 10 & Table 6). This gives green infrastructure planning a broader basis than might otherwise be the case – including, for example, considerations relating to multiple-use forestry and urban agriculture. Thus, Berlin has an effective, comprehensive and well-integrated green infrastructure planning program. The overall outcome is that Berlin's greening policies and programs are now regarded as among the most advanced in the world (SBEnrc 2012). Clearly, it is also a model for green infrastructure planning. Three important properties have emerged from this case study. First, green infrastructure planning is integrated within the statutory land use planning process; second, it has a sound ecological basis; and third, it gives expression to multifunctionality and connectivity.

6. General planning principles for green infrastructure

6.1 Existing principles: selected examples

This section presents a selection of views as to what constitutes 'general principles for green infrastructure planning'. Publications were selected from UK, US and European authors with the intention of illustrating the diversity of views[13]. Selections were made only from literature spanning the last 10 years (2006 to 2016), although it is recognised that the origins of green infrastructure planning go back at least to the late 1980s - early 1990s, and its antecedents even

[13] This is not intended to be a comprehensive review of green infrastructure planning principles, rather it is a 'snapshot' of contemporary approaches. Authors presenting such principles and guidelines and not discussed here include Benedict and McMahon (2002; 2006); Ahern (2007); Landscape Institute (2013); Ely and Pitman (2014).

further, possibly to the seminal works of McHarg (1969) and Hackett (1971) (Kambites & Owen 2006). An even longer view is taken by some authors (e.g. Rouse and Bunster-Ossa 2013).

So starting from 2006, the first set of planning principles are those provided by Kambites and Owen (2006). These authors view green infrastructure planning as 'more complex, in both subject matter and process, than conventional open space planning—and potentially more effective in enhancing liveability for human communities while nurturing the intrinsic values of the natural environment' (Kambites & Owen 2006, p.484). They put forward 10 principles derived from approaches developed in the UK and USA (Table 7). Hence, this can be taken as something of a summary to the year 2006. While the UK principles tend to be socially based, the US principles tend to have an ecological focus. Nonetheless, they are not considered 'inherently contradictory' (Kambites & Owen 2006, p.486). However, notwithstanding the mention of 'linkages' and 'multifunctionality', these principles are unexceptional and could apply to landscape planning in general, indeed, most of those listed could also apply to urban planning. A more 'green infrastructure specific' set of principles is provided by Rouse and Bunster-Ossa (2013). They suggest that six principles inform the planning and design of green infrastructure across different disciplines and scales of professional practice. In contrast to the generality exhibited in Kambites and Owen (2006) suggestions, these are better targeted. Table 8 provides a summary. Rouse and Bunster-Ossa's suggestions as to how these principles can be applied across landscape scales, from region to site, are particularly useful (Rouse and Bunster-Ossa 2013, p.24-25). Their approach to planning, particularly in identifying connectivity as a planning principle along with an emphasis on 'multi-scale linkages', reflects some elements of what could be termed a 'landscape ecological perspective' on green infrastructure planning. In addition, their view of green infrastructure operating 'as part of a hierarchy of nested systems, each of which contains stocks of assets held together by interconnections (flows and interactions between systems)' (Rouse and Bunster-Ossa 2013, p.15), also reflects this perspective, specifically hierarchy theory (see Forman 1995a).

The landscape ecological perspective has its roots in the work of Forman and Godron (1986), Forman (1995a; 1995b) and Dramstad, Olson and Forman (1996), and has been applied in the context of urban green infrastructure by Ahern (2007). Ahern puts the view that green infrastructure plans should 'apply key principles of landscape ecology to urban environments, specifically: a multi-scale approach with explicit attention to pattern-process relationships, and an emphasis on connectivity' (Ahern 2007, pp.267). As already noted, the notion of connectivity appears in the principles enunciated by Kambites and Owen (2006), and both the multi-scale approach and connectivity have been expressed in the principles set-out by Rouse and Bunster-Ossa (2013), however, reference to pattern-process relationships appears absent in both. Nonetheless, Rouse and Bunster-Ossa (2013) do reference this relationship in a tangential way via the connectivity principle – in referring to the need for a 'physically connected landscape-scale system' (with functional linkages) they are invoking the idea of ecological networks. The latter is one manifestation of attempts to come to grips with the pattern-process relationship (Ahern 2007, p.270).

Table 7: Principles of green infrastructure planning according to Kambites and Owen (2006)*

Principle	Summary description
1. Comprehensive planning	GI should ideally be planned in advance of, or concurrently with, the built environment.
2. Information collation	Extensive information collection relating to ecological, historical, social and visual matters should be undertaken to guide GI development.
3. Holistic approach	The development should be considered as a whole, on a number of different levels including: *Geographically:* each individual area of green space (or hub) should be linked via a network of 'corridors'. *Politically:* all relevant local authorities should work together to create a unified vision that can overlap administrative boundaries. *Functionally:* the resulting GI should be multifunctional, benefiting both people and wildlife.
4. Linkage	Links between natural areas and features, and between people and programmes, should be created.
5. Community involvement	Interest groups, stakeholders and others such as minority and disadvantaged groups should be involved, as this will ensure that development has a degree of ownership for those living within the surrounding area.
6. Recreational needs	The development should meet residents' needs for recreational opportunities and green routes/corridors.
7. Conservation	Where possible the development should protect, restore and create habitats and ensure that all designated sites are conserved.
8. Respect for the site	By incorporating existing characteristics and features the development will exhibit a greater degree of diversity and identity.
9. Local distinctiveness	Local character and distinctiveness should be identified, enhanced and protected wherever possible.
10. Sustainable funding	Financial support for the development of GI should be sourced at an early stage and particular attention should be paid to longer-term issues such as maintenance and improvement.

* throughout this table and the following tables (8 and 9) the acronym 'GI' stands for 'green infrastructure'.

Table 8: Principles of green infrastructure planning according to Rouse and Bunster-Ossa (2013)

Principles	Summary description
1. Multifunctionality	– builds on the concept of the triple bottom line i.e. the environmental, economic, and community benefits provided by green infrastructure. – calls on planners and designers to achieve seemingly disparate goals such as flood control, reduced dependence on imported energy, and improved public-health outcomes.
2. Connectivity	– GI is most effective in providing services and benefits when it is part of a physically connected landscape-scale system. – to create a connected GI system at the landscape scale, need to establish physical and functional linkages across urban, suburban, and rural landscapes and across scales to connect site, neighbourhood, city, and region.
3. Habitability	– this principle positions GI as visible space that provides outdoor habitat for people, flora, and fauna. – central to the idea of habitable GI is the need to foster conditions in which people can be healthy e.g. improved air and water quality, increased opportunity for outdoor recreation and exercise.
4. Resiliency	– GI can increase community resiliency (ability to recover from or adapt to disturbance and change) over short and long timeframes e.g. reduced damage and faster recovery from natural disasters, increased ability to adapt to climate change.
5. Identity	– this principle addresses the potential of GI to contribute to the visual definition of a place. – could a recurring motif expressed through stormwater or other forms of green infrastructure help visually define a neighbourhood, city, or region?
6. Return on investment	– this principle calls for a demonstration as to how GI can reduce costs and yield positive financial outcomes for governments, institutions, businesses, and citizens.

A more recent attempt to provide planning principles for green infrastructure is provided by Quintas (2015). This author first suggests that in metropolitan landscapes the planning methodology for green infrastructure should be carried out at 2 levels viz. strategic urban green infrastructure for the entire metropolitan area; and operative urban green infrastructure at the municipal urban level. Then, 4 general principles are put forward (Table 9). They are intended for application to a green infrastructure system or the individual elements which comprise it. This a useful and succinct set of principles. The influence of landscape ecology can be detected throughout, and is clearly indicated by the in-text citations. Some examples – *quantity* refers (among other things) to size of green infrastructure elements (Table 9). Here, Quintas recognises that such elements (see Table 3) are, from the viewpoint of landscape ecology, a 'patch' in the landscape (urban or rural) and that the size of that patch determines, to a large

extent, ecological values (see Forman 1995a)[14]. Design guidelines for patch size are set-out in Dramstad, Olson and Forman (1996, pp.19-25). As for the *continuity* principle (Table 9), it appears synonymous with 'connectivity', the latter, again, deriving from landscape ecological principles and as noted in Sec. 3 as a key characteristic of green infrastructure (as for 'size', design guidelines for continuity/connectivity are provided in Dramstad, Olson and Forman 1996). In regard to *context*, Quintas notes that it 'affects not only the functioning of the green infrastructure system, but also each individual element, leading to the complementariness of functions in the articulation of systems and space' (Quintas 2015, p.189). Again, this draws on landscape ecology, the ecological importance of context being expressed in Forman's statement with respect to 'principles in a generic plan' (Forman 1995a, pp.449-452).

Table 9: Principles of green infrastructure planning according to Quintas (2015)

Principle	Summary description
Quantity	– relates to the proportions, availability and distribution of green infrastructure – for individual GI elements focusses on size – what size (e.g. surface area) is required for an element to preform its inherent functions? – also refers to number and availability of spaces and species.
Quality	– quality is related to diversity and equity, which result from the heterogeneity and spatial distribution of GI elements. – diverse green infrastructure is generally more valued, performing more functions and having the greatest potential for promoting quality of life.
Continuity	– enables the occurrence of specific processes and functions through proximity of one element to another, resulting in more cohesive and interdependent systems. – continuity can be structural or functional. – is essential to promote continuity between GI elements, as well as create linkages with other urban systems and the broader landscape.
Context	– determined by the relationship between systems and the 'outside', since all systems are regulated both by intrinsic and extrinsic factors. – can be spatial (relative location) or functional (based on services provided). – affects not only the functioning of the green infrastructure system, but also each individual element.

The preceding illustrates something of the diversity of views in regard to general principles for green infrastructure planning. Notwithstanding this diversity, the influence of landscape ecology is pervasive, particularly in regard to connectivity. It is also interesting to note that the most recent attempt to define principles (Quintas 2015) goes well-beyond the first

[14] A patch is a relatively homogeneous non-linear area that differs from its surroundings (Forman 1995a). It sits within a 'matrix' (a background ecosystem or land use type) and may be connected to other patches by corridors (a strip of a particular type that differs from the adjacent land on both sides). The pattern of patches, corridors and matrix is a 'mosaic'.

(Kambites & Owen 2006) in drawing on landscape ecology. This may represent the well-known 'lag-time' in the translation of scientific principles to professional fields like planning. Nonetheless, much more work needs to be done in this area. One promising avenue of investigation is in using spatial concepts from landscape ecology as a basis for green infrastructure systems. As Ahern (2007, p.273) notes: 'Spatial concepts are essential tools for proactive, or innovative planning, and can structure and inspire the planning process, particularly with respect to achieving genuine and effective public participation'. Of particular relevance are Forman's (1995a) 'indispensable patterns'. Ahern comments that they 'are perhaps the most succinct, compelling and memorable of the landscape ecology-based guidelines', and furthermore, 'are equally relevant in urban environments as they are in landscapes that are less dominated by human development and built infrastructure' (Ahern 2007, p.272)[15]. Can these sorts of patterns be fully realised through green infrastructure planning? Certainly, elements of indispensable patterns do appear in various recent case studies (e.g. Landscape Institute 2013; Rouse and Bunster-Ossa 2013; Firehock, 2015). How far this has been taken, and the conditions under which such patterns manifest, is an area requiring further investigation (see Sec. 7).

6.2 Suggestions for additional principles

The influence of landscape ecology on green infrastructure planning is readily apparent in the preceding review of planning principles, and as pointed out in earlier in this paper, on the concept of green infrastructure itself. Is there a 'big picture' planning principle which gives explicit recognition to the understandings deriving from landscape ecology beyond that of multifunctionality, connectivity and the multi-scale approach? The following general principle is proposed in view of the potential importance of spatial concepts as noted above. Strategies, that is, actions to implement the principle are also provided. These are based on Forman's description of the key elements of indispensable patterns (Forman 1995b, p.140).

Principle 1: Green infrastructure planning should emulate 'indispensable patterns' in both urban and rural landscapes.

This principle provides a clear directive without being overly prescriptive – 'emulate' meaning 'an *attempt* to match' (or even surpass). Strategies to achieve this are as follows:

- retain and/or rehabilitate natural vegetation patches, include more than one at any landscape scale, and maximize their size;
- protect water courses with vegetated corridors, maximising their width;
- provide for functional connectivity for key species between large patches; and
- provide small heterogeneous patches and corridors throughout developed areas.

[15] Indispensable patterns are described by Forman (1995b, p.140) as: 'Top-priority patterns for protection, with no known substitute for their ecological benefits, are a few large natural- vegetation patches, wide vegetated corridors protecting water courses, connectivity for movement of key species among large patches, and small patches and corridors providing heterogeneous bits of nature throughout developed areas'. According to Ingegnoli (2002, p.286) indispensable patterns are one of 8 key landscape ecological principles relevant to planning. They are also one of 3 components of the 'spatial solution', the latter described as a 'pattern of ecosystems or land uses that will conserve the bulk of, and the most important attributes of, biodiversity and natural processes in any region, landscape, or portion thereof' (Forman & Collinge 1997, p.129).

In regard to the Berlin case study, a key feature is the integration of green infrastructure planning within statutory land use planning process. This is not addressed in any of the principles noted in the preceding or in the principles and guidelines enunciated by others (e.g. Benedict and McMahon 2002; Ahern 2007; Landscape Institute 2013; Ely and Pitman 2014)[16]. On the other hand, the other features identified viz. an ecological basis for green infrastructure planning, and the latter giving expression to multifunctionality and connectivity, are referenced in one or more of the principles reviewed. For example, 'providing an ecological basis' is addressed in Principles 2 (Information Collation) and Principle 7 (Conservation) in Kambite and Owen (2006) (see Table 7), and in the Quantity, Quality and Context principles suggested by Quintas (2015) (see Table 9). As for multifunctionality and connectivity, they are directly addressed by Rouse and Bunster-Ossa (2013) in Principles 1 and 2 (see Table 8).

The following additional principle is proposed to address the important, but unaddressed issue of integration. Strategies are also proposed.

Principle 2: Green infrastructure planning should be aligned with statutory land use planning.

A complete integration of the green infrastructure planning process within the statutory land use planning process (as in the Berlin case) would involve a change in the legal framework of the jurisdiction under question. This is probably not a practical suggestions in many instances, hence Principle 2 calls for an 'alignment'. This is much less prescriptive than calling for 'integration', and allows for some discretion with respect to strategy. This could mean, for example, simply encouraging and facilitating the use of non-statutory plans in the statutory planning process. This is already done in many Australian planning jurisdictions in utilising agricultural suitability maps, land capability maps and catchment management plans in the planning process. So, green infrastructure plans would be added to the list of plans that may (or may not) be taken into account in the statutory planning process. More detail on how this can be done in the US context is provided by Rouse and Bunster-Ossa (2013) and Firehock (2015).

Rouse and Bunster-Ossa (2013, pp.145-154) also provide a model regulatory framework for green infrastructure. This is possibly the most expedient way to action Principle 2, notwithstanding the fact that a regulatory approach is via development control planning, when green infrastructure is desirably a strategic planning activity.

Undoubtedly, the question of how to align green infrastructure planning within the statutory land use planning process is a complex one, and a topic which deserve further research (see following section). For now, the two strategies noted in the preceding are put forward:

- encourage and facilitate the use of non-statutory green infrastructure plans in the statutory land use planning process; and

[16] Benedict and McMahon (2002, p.16) list the benefits arising from an integration of green infrastructure in the land planning process, suggesting that it 'enables conservation and development to be planned in harmony'. However, such integration is not expressed as a planning principle.

– develop regulatory frameworks for green infrastructure

For the first, much is dependent on the creativity of planners, and the interest and involvement of the community. The latter is an aspect emphasised by Firehock (2015). The second strategy applies mainly to local-area planning, and falls under the aegis of development control planning rather than strategic planning per se - clearly, the implication of this needs to be thought through. An overriding conceptual issue is that the nature and characteristics of green infrastructure clearly places the planning of it within sustainable land use planning, rather than within land use planning and development control planning (Table 10). Unfortunately, in many situations green infrastructure planning needs to fit within the latter two categories, with the inevitable comprises given the focus and objectives of those categories. Berlin has managed to avoid this by building green infrastructure planning into the statutory land use planning process (see Lachmund 2013). The situation in most cities is that green infrastructure planning must be considered an 'add-on' to an existing and often well-entrenched planning process.

Table 10: Categories of planning and their main differences

	Development Control	**Land Use Planning**	**Sustainable Land Use Planning**
Focus:	built environment, with an urban focus	land and its suitability for certain uses; focus can be urban or rural	the socio-ecological system and land within this broader context
Implemented via:	Land use zoning and development standards	a range of statutory and non-statutory plans (e.g. land capability maps; agricultural suitability; and catchment management plans)	a wide variety of policies, plans and programs
Objectives:	consistency in developments	use/development matching the attributes of the land	sustainable development

7. Further research questions

The following general and Berlin-specific questions have arisen in the course of this study. These could provide a focus for further research in the area of green infrastructure planning.

a) General questions:

– Green infrastructure planning and biophilic urbanism. Some pertinent questions are: Is there a nexus between green infrastructure planning and biophilic urbanism? If so, what kind of planning regimes engender biophilic urbanism, or does the latter provide an impetus for green infrastructure planning?

- Landscape ecological principles and green infrastructure planning. How well are landscape ecological principles integrated within contemporary green infrastructure planning? Are there particular conditions (social and ecological) favourable to the creation of the spatial patterns drawn from landscape ecology?
- Green infrastructure planning and the statutory land use planning process. How to align the former with the latter within an existing legal framework? What are the strategic implications of placing green infrastructure planning within a regulatory framework?

b) Berlin-specific questions:

- How well connected are Berlin's green infrastructure assets? Strictly speaking, an isolated city park is not green infrastructure unless connected to other green infrastructure components. However, the literature tends not to be overly concerned with this caveat, with greenspaces typically considered as components or green infrastructure irrespective of whether they are connected or isolated. This view has been adopted in this paper, although it would be useful to describe green infrastructure components as either 'connected' or 'unconnected', notwithstanding possible difficulties in ascertaining the 'functional connectivity' described earlier in this paper. A remote survey of Berlin to ascertain at least the physical connectivity between major green infrastructure assets would be a useful step forward, particularly in the context of a comparative study across several cities (as noted below).
- What developments are occurring with respect to linking urban green infrastructure with the regional landscape? In other words, is the 'multiscale approach' discussed earlier in this paper evident in the Berlin-Brandenburg Region? If so, how is this achieved within the current planning regime?

From a broader perspective, there is also a need for a comparative case study between cities. This is because, as Mell (2016) points out, that while research on green infrastructure has grown rapidly in the last decade, studies across locations are relatively rare. The more usual approach is for authors to contextualise 'their understanding of green infrastructure in a single location' (Mell 2016, p.4). Examples of this include Rouse and Bunster-Ossa (2013), Austin (2014), and Firehock (2015). Even when comparative studies are carried out, the focus is generally on Europe and North America (e.g. Mell 2016). Asia is typically considered as a separate entity (e.g. Newman & Matan 2013). Similarly, Australia tends to be treated separately (e.g. Beatley and Newman 2009), as is Africa (e.g. Abbott, 2012). A study is needed which takes a broader view, drawing on examples of green infrastructure planning from the Northern Hemisphere (Berlin), the tropics (e.g. Singapore), and Southern Hemisphere (e.g. Melbourne). These cities are set within very different biophysical, social and cultural contexts. Thus, they represent something of the wide variation in the urban contexts in which green infrastructure planning takes place.

The potential significance of the aforementioned study is that it addresses the 'across location' deficiency in research. In addition, a north-south 'transect' is proposed (Europe-Asia-Australia),

in contrast to the usual east-west approach (UK, Europe, and North America) (e.g. Mell 2016). This means a more varied environmental gradient is traversed – the most obvious example being climate types, which, in broad terms, range from 'mid-latitude' to 'tropical'.

8. Summary

8.1 Concept, definition, key characteristics and components

There are a number of views on the origin of the term 'green infrastructure'. Sandström (2002) suggests that it was first introduced by Charles Little in the USA – Little had described an extensive system of greenways as 'an entirely new infrastructure category' (Little 1990, p.30). The concept gained further attention in the context of sustainable development, when it was thought necessary to upgrade the status of urban green space to 'green infrastructure', thus putting it on equal footing with other 'physical urban structures' i.e. grey infrastructure (Sandström 2002, p.380). Since that time the term has appeared frequently in the environmental planning and design literature, and there is a broad awareness of the concept and the values of urban green space, particularly in the area of climate change adaptation.

There are numerous definitions of green infrastructure. One of the earliest and most frequently cited is provided by Benedict and McMahon (2006). They define it as 'an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife' (Benedict and McMahon (2006, p.1). There are more recent definitions, for example: green infrastructure is 'the network of green places and water systems that delivers multiple environmental, social and economic values and services to urban communities' (VISES 2015, p.3), or 'the green spaces and water systems which intersperse, connect and provide vital life support for humans and other species within our urban environments' (Ely and Pitman 2014, p.3).

A review of 14 definitions over the past 10 years, reveals two recurring elements - *multifunctionality* and *connectivity* – these lend some commonality to what may at first appear as disparate definitions. In summary, multifunctionality represents the ability of green infrastructure 'to provide several ecological, socio-cultural, and economic benefits' (Hansen et al. 2015, p.9). It is considered central to the green infrastructure approach, applying to such diverse areas as habitat provision and access to nature; recreation, movement and leisure; landscape setting and context; and flood attenuation and water resource management (Natural England 2006, p.22). Multifunctionality has been comprehensively described by the European Commission (2012). A broad range of potential benefits have also been identified (European Commission 2013). These fall into 4 categories, namely, environmental (e.g. provision of clean water); social (e.g. better health and human well-being); climate change adaptation and mitigation (e.g. carbon storage and sequestration); and biodiversity (e.g. improved habitats for wildlife) (see Table 2). Certainly, multifunctionality can be considered a key characteristic of green infrastructure, its importance underscored by the fact that it has been identified as a planning principle (e.g. Rouse and Bunster-Ossa 2013).

The other common characteristic is connectivity. Two forms are recognised - 'structural' and 'functional' (Forman 1995a). The first is a measure of spatial continuity (of landscape

elements), while the latter refers to how connected an area is for a process. Connectivity is also considered a planning principle by Rouse and Bunster-Ossa (2013). In the simple green infrastructure 'hubs and links model', connectivity is about linking hubs to form a network (Benedict & McMahon 2002). It is also about creating *multi-scale links* to 'establish physical and functional linkages across urban, suburban, and rural landscapes and across scales to connect site, neighbourhood, city, and region' (Rouse & Bunster-Ossa 2013, p.19-20). This 'multi-scale approach', with an emphasis on connectivity, is an application of certain key principles deriving from the field of Landscape Ecology (Ahern 2007). Insights from the latter are appearing in recent publications on green infrastructure planning, suggesting that early reservations regarding the application of landscape ecology to planning (e.g. Hobbs 1997; Bastian 2001) may be unfounded.

The critical contribution of green infrastructure to the three components of sustainability viz. environment, economy and equity, is now well-recognised (e.g. Quintas 2015). The multifunctional nature of green infrastructure is pivotal in this role, whether one is considering functions or benefits.

The components of green infrastructure e.g. public parks and gardens, greenways, and waterways, comprise various elements – for example, public parks and gardens comprise urban parks, open space reserves, cemeteries and formal gardens, while greenways can include river and creek corridors, cycleways and routes along major transport corridors. These components and elements can be collectively termed 'green infrastructure assets'. They take many forms (see Table 3), range across landscape scales, have diverse origins, and can be found in both urban and rural landscapes.

8.2 Green infrastructure planning and Berlin case study

Green infrastructure planning has been described as 'a strategic planning approach that aims at developing networks of green and blue spaces in urban areas designed and managed to deliver a wide range of ecosystem services' (Hansen et al. 2015, p.9). It aims to create multifunctional networks across landscape scales, from regional to city to neighbourhood. It can be viewed as an activity within the field of landscape planning, the latter one of the major areas of environmental planning (see Figure 1). Green infrastructure planning has links to urban planning, regional development planning and social planning.

The case study city, Berlin, is Germany's largest city and centre of the Berlin-Brandenburg Metropolitan Region. It is located in north-eastern Germany. The city has a strong focus on green infrastructure planning and has 'some of the most advanced and sophisticated urban greening policies and programs in the world' (SBEnrc 2012, p.21). In many ways, it offers an exemplary example of green infrastructure planning, and as such offers an opportunity to identify general planning principles.

Berlin's green infrastructure assets are spread across the full range of land use types (see Table 4). In some instances they represent the whole land use type, in other cases they are present as particular components or elements. The former include agriculture, woodland and water, amounting to 29.2% of the total area. For the latter, one example is the land use category

'buildings'- this will include green roofs and walls, interior courtyard and balcony gardens. The city's green infrastructure has been categorised in a number of ways – for example, whether it is 'designed', 'natural' or 'made by people' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015) (see Table 5).

Overall, some 44% of Berlin's total urban area consists of green spaces and waterways (Profé et al. 2012, p.7). This includes more than 2,500 public green and recreation spaces occupying some 6,400ha. In terms of green area per million people, Berlin has more than six times that of Melbourne, and more than 4 times that of Sydney (UN-Habitat 2016, p.210). Key drivers in the development of Berlin's green infrastructure are considered to be an historical and cultural concern for the environment; the urban heat island effect; a focus on quality of life; and waterway protection (SBEnrc 2012).

Berlin is involved in regional planning with the surrounding State of Brandenburg. The State Development Programme for the Berlin-Brandenburg Region is the overall planning strategy for the region. Important provisions from a green infrastructure perspective include regional parks to protect the peri-urban landscape from urban sprawl, in addition to conserving land for recreational purposes (Hansen 2015). For Berlin itself spatial planning ranges across scales, from city-wide to city-block. The centrepiece at the city-wide scale is the Land Use Plan, which provides for the future development of the city, showing which parts of the city are intended for housing, industry, commerce, infrastructure and other urban uses. Its also shows which areas are to be retained as open space. The hierarchy of plans, from regional to local area, is shown in Figure 10.

Hansen's (2015) recent analysis of Berlin's green infrastructure planning is deficient in that it does not explicitly recognise the central role of the Land Use Plan. It is this plan which contains an open space strategy which aims to 'knit together' the open space pattern by using a 'large number of green corridors' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). This is clearly an expression of connectivity, one of the key characteristics of green infrastructure identified in Section 3. Multifunctionality is also given expression, since the Plan will improve accessibility to 'large recreational landscapes on the outskirts of the city from major housing areas' and provide for green corridors along watercourses (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). In short, the Land Use Plan provides the framework for a city-wide green infrastructure characterised by both connectivity and multifunctionality.

Plans based on Berlin-specific environmental legislation are also important in the planning of green infrastructure. Here, the Landscape Programme (LaPro) is of particular significance. It deals with the protection of natural resources, open spaces, conservation, and the improvement of living conditions for the inhabitants. It also provides the ecological basis for the Land Use Plan and is a key element in linking landscape planning (and green infrastructure planning, as part of that) with the statutory land use planning process.

The strength of Berlin's green infrastructure planning lies in the fact that is embedded within the statutory planning process via the city's Land Use Plan. Importantly, the latter is informed by the Landscape Programme, which also has statutory weight and 'provides the major basis for

ecological considerations relevant to the Land Use Plan' (Senatsverwaltung für Stadtentwicklung und Umwelt 2015, p.14). Green infrastructure planning is also informed by a number of informal plans, again via the Land Use Plan (see Figure 10), giving it a broader basis than might otherwise be the case. Considerations include climate change adaptation, social functions of urban green space, urban agriculture, and multiple-use forestry (see Table 6).

Overall, Berlin has an effective, comprehensive and well-integrated green infrastructure planning program. Three important properties have been identified: first, green infrastructure planning is integrated within the statutory land use planning process; second, it has a sound ecological basis; and third, it gives expression to multifunctionality and connectivity.

8.3 General planning principles: existing and suggested

Three examples of green infrastructure planning principles spanning the years 2006 to 2016 were reviewed (principles summarised in Tables 7, 8 and 9). These illustrate something of the diversity of views in regard to general principles. Notwithstanding this diversity, the influence of landscape ecology is pervasive, particularly in regard to connectivity. The most recent attempt to define principles (Quintas 2015) goes well-beyond the first (Kambites & Owen 2006) in drawing on landscape ecology. One avenue of further investigation is suggested to be in using spatial concepts from landscape ecology as a basis for green infrastructure systems.

Two additional planning principles (along with strategies) have been suggested. The first is: green infrastructure planning should emulate 'indispensable patterns' in both urban and rural landscapes; and the second: green infrastructure planning should be aligned with the statutory land use planning process.

8.4 Further research questions

A number of general and Berlin-specific research questions have been put forward. These relate to green infrastructure planning and biophilic urbanism; green infrastructure planning and landscape ecological principles; green infrastructure planning and the statutory land use planning process; and for Berlin, connectivity across its green infrastructure assets, and the multi-scale approach in the Berlin-Brandenburg Region.

It is also suggested there is a need for a comparative case studies between cities, since studies across locations are relatively rare. In particular, a study is needed which draws on examples of green infrastructure planning from the Northern Hemisphere (Berlin), the tropics (e.g. Singapore), and Southern Hemisphere (e.g. Melbourne). The significance of a study of this kind is that it would addresses the 'across location' deficiency in research, and in addition, do this along a N-S 'transect' (an approach which hasn't been adopted to-date).

9. Conclusion

This study has clarified the nature and characteristics of green infrastructure and green infrastructure planning. While there are numerous definition of green infrastructure, it is possible to say that it comprises a network of green spaces and water features. These spaces may be natural or semi-natural, can be found in situ, or created/recreated in both urban and

rural landscapes at a variety of scales (neighbourhood, suburb, city and region). Multifunctionality and connectivity are its two key characteristics.

Green infrastructure planning aims to create multifunctional networks across landscape scales. It is a strategic planning approach. A central concern is connectivity – linking the various components and elements of green infrastructure together, in ways that are beneficial to humans, other species and the abiotic component of the environment. Berlin provides an exemplary example of such planning, showing a close integration within the statutory land use planning process, a sound ecological basis, and a concern with multifunctionality and connectivity.

General planning principles for green infrastructure have also been identified from the literature. The selected examples are diverse in the issues addressed. Nonetheless, they do show the pervasive influence of landscape ecology, particularly in regard to connectivity. The first of two suggested additional principles draws on landscape ecology to propose that a spatial concept i.e. indispensable patterns, be used as a model for the patterning of green infrastructure. The second principle draws on the Berlin case study to call for an alignment of green infrastructure planning with statutory land use planning.

Research questions have been identified in a number of general and Berlin-specific areas. However, possibly the most pressing need is for a comparative case study of green infrastructure planning between cities. Studies of this kind are rare, despite a rapid increase in green infrastructure research over the last decade.

Clearly, green infrastructure is a significant and increasingly influential concept. In dealing with this complex and multi-faceted concept, green infrastructure planning has several significant challenges, one of the more important is how to integrate it within the statutory planning process, or at the very least, how to maximise its influence on that process. At stake is not only the continued implementation of sustainable development, but also progress in the urgent task of climate change mitigation and adaptation.

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